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Rainfall simulations of land management practices in the Normanby and Endeavour River catchments

JUNE 2015

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June 2015

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Cover Figure: Rainfall simulator set up at the grazing sodic duplex soil site (gully head)

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List of Acronyms

DIN	Dissolved inorganic nitrogen (sum of ammonia-N and NO_x-N)
GBR	Great Barrier Reef
N	Nitrogen
NATA	National Association of Testing Authorities
NO_x-N	Nitrogen oxides (sum on nitrate and nitrite, but mainly nitrate)
Ortho-P	Ortho-phosphate (inorganic forms of phosphate)
P	Phosphorus
TKN	Total Kjeldahl nitrogen (sum of ammonia-N and organic based nitrogen)
TN	Total nitrogen (sum of TKN and NO_x-N)
TP	Total phosphorus
TSS	Total suspended solids

EXECUTIVE SUMMARY

The Normanby River and Endeavour River are two river systems flowing into the Great Barrier Reef lagoon. The Normanby Basin is the fourth largest on Cape York (~24,200 km^2), while the Endeavour River catchment is much smaller (1315 km^2). Cattle grazing is the most extensive land use across both catchments, with areas of horticulture occurring on the rich red basalt soils around Lakeland (Normanby Basin) and along the Endeavour River. Previous water quality studies have shown elevated levels of sediments and nutrients associated with these land use developments, particularly in the Normanby Basin. Further details on the basin characteristics and water quality issues can be found in reports from other studies.

A rainfall simulation study was undertaken in April 2015 to provide supporting data for extension activities in grazing and horticulture across the Cape York region. Simulated rainfall was used to assess and compare the runoff and water quality from various soil types and management practices (including grazing, horticulture and internal property roads) within the Normanby and Endeavour River catchments. Simulations were undertaken on a combination of 19 differing soil type/land use/management practice combinations, and are summarised in the table below.

Site	Soil name (Great Soil Group)	Soil concept	Land management practices studied
Horticulture properties			
Lakeland	Burn (Euchrozem / Krasnozem)	Deep uniform red structured clay soils with nodules formed on basalt	Banana (row and interrow), cropping (fallow) and pasture (ungrazed)
Endeavour Valley	Endeavour (Krasnozem / Euchrozem)	Deep gradational or occasionally uniform red structured soil formed on basalt	Dragon fruit (row and interrow) and star apple (row and interrow)
Grazing properties			
Yellow earth	Clark (Yellow Earth)	Deep bleached gradational yellow massive soils on residual sands	Pasture and road
Red earth	Emma (Red Earth)	Deep gradational massive red soils formed on sandstone	Pasture (ungrazed) and road
Brown earth	Myall (Xanthozem)	Deep uniform or gradational yellow structured clay soils formed on siltstone, mudstone or claystone	Pasture and road
Sodic soil	Hann (Soloth / Gleyed Podzolic)	Deep bleached duplex soils on footslopes and drainage depressions in residual sands	Pasture and road
Sodic duplex soil	Gibson (Solodic / Soloth)	Deep duplex sodic yellow or grey soils on colluvia and pediments from greywacke and slate	Pasture, road and gully head

Simulated rainfall was applied to each plot at a rate of approximately 80 mm/hr for one hour. Runoff rates were manually measured from the outlet of each plot by recording the time taken to fill a measured volume. Water quality samples were collected at 5 or 10 minute intervals (6 samples collected from each simulation run), depending on when runoff commenced. Water samples were chilled on collection, and sub-sampled and filtered at the end of each day. Nutrient samples were then frozen, and the sediment samples kept cool, and submitted to the laboratory for analyses (electrical conductivity, sediment and nutrient (total and filtered) concentrations).

Water quality loads (kg/ha) and event mean concentrations (EMC; mg/L) were calculated for each parameter. The summarised runoff and water quality loads for each simulation plot are presented below.

Site	Runoff (mm)	TSS (kg/ha)	TP (kg/ha)	Ortho-P (kg/ha)	TN (kg/ha)	TKN (kg/ha)	Ammonia-N (kg/ha)	NO_x-N (kg/ha)
Horticulture properties								
Banana row	0	-	-	-	-	-	-	-
Banana interrow	49	1120	3.05	0.13	5.82	5.63	0.04	0.19
Cropping	31	673	1.55	0.03	2.87	2.83	0.03	0.04
Pasture	0	-	-	-	-	-	-	-
Dragon fruit row	54	48	0.09	0.07	0.68	0.60	0.02	0.09
Dragon fruit interrow	59	53	0.03	0.03	0.39	0.36	0.01	0.03
Star apple row	20	36	0.01	<0.01	0.22	0.21	<0.01	0.01
Star apple interrow	51	131	0.16	0.01	1.72	1.68	0.01	0.04
Grazing properties								
Yellow earth (pasture)	21	106	0.02	0.01	0.45	0.44	<0.01	0.02
Yellow earth (road)	72	2950	0.24	0.10	1.51	1.42	0.03	0.09
Red earth (pasture)	0	-	-	-	-	-	-	-
Red earth (road)	63	199	7.69	0.89	1.06	1.03	0.05	0.04
Brown earth (pasture)	10	24	0.01	<0.01	0.15	0.14	<0.01	0.01
Brown earth (road)	77	2880	1.90	0.01	11.0	10.9	0.20	0.16
Sodic soil (pasture)	20	93	0.02	0.01	0.22	0.20	<0.01	0.02
Sodic soil (road)	68	2580	0.12	0.05	1.31	1.24	<0.01	0.06
Sodic duplex (pasture)	48	221	0.20	0.02	1.08	1.07	0.02	0.01
Sodic duplex (road)	74	3650	1.05	<0.01	2.90	2.88	0.03	0.02
Sodic duplex (gully head)	80	9260	2.54	<0.01	7.94	7.93	0.03	0.03

It should be noted that reported concentrations of TN are derived by calculation (TKN+NO_x-N). Due to non-detections, in some instances, TN may be reported as being lower than TKN. As a result, calculated loads may also be lower (or TKN+NO_x-N is different to TN).

In summary, these results highlight:

- Runoff - the combination of soil types and management showed that uncompacted highly permeable soils did not run off (banana row and ungrazed pastures), ranging up to almost 100% runoff from a scalded gully head on a sodic duplex soil.
- Sediment loss (TSS) - sediment loss from those plots that ran off ranged from 24 kg/ha (brown earth pasture; low runoff) to 9260 kg/ha (gully head on sodic duplex soil; high runoff and sediment concentration). Roads produced at least 16 times more sediment loss than pasture sites on the same soil type due to more runoff and higher sediment concentrations. The gully head on the sodic duplex soil produced ~42 times more sediment loss than the pasture site on the same soil. These results highlight the need for erosion management of roads, and maintaining pasture cover on fragile sodic soils to prevent gully initiation.
- Nutrients - total N and P loads in runoff from horticultural sites were within the range of the loads measured from the pasture sites. Roads produced more TN and TP than pasture, due to the higher runoff and sediment concentrations. The elevated TKN (and therefore TN) loads from the brown earth road may be due to the influence of cattle excrement. Runoff of nitrogen and phosphorus was dominated by organic forms at all sites, except the dragon fruit site which may have been due to applied fertiliser.

In summary, the results of this rainfall simulation study are supported by those observed from other studies. The results highlight the potential for elevated sediment and nutrient runoff losses if the soil type is not managed appropriately.

1. INTRODUCTION

The Normanby River and Endeavour River are two river systems flowing into the Great Barrier Reef lagoon (Figure 1). The Normanby Basin is the fourth largest on Cape York (~24,200 km^2), while the Endeavour River catchment is much smaller (1315 km^2). Cattle grazing is the most extensive land use across both catchments, with areas of horticulture occurring on the rich red basalt soils around Lakeland (Normanby Basin) and along the Endeavour River. Previous water quality studies have shown elevated levels of sediments and nutrients associated with these land use developments, particularly in the Normanby Basin. Further details on the basin characteristics and water quality issues can be found in reports from other studies (e.g. Brooks et al., 2013; Howley et al., 2013).

Rainfall simulators allow for the creation of simulated rainfall events of known properties (e.g. intensity and duration), providing an opportunity for increased control over the many variables that govern natural rainfall. By delivering rainfall when and where it is required, and under the specific conditions of interest, it allows a comparison of land use and land management practices across a wide geographical area.

A rainfall simulation study was undertaken in April 2015 to provide data for supporting extension activities in grazing and horticulture across the Cape York region by:

- Assessing and comparing the runoff and water quality from various soil types and management practices (including grazing, horticulture and internal property roads) within the Normanby and Endeavour River catchments; and
- Comparing and contrasting the simulation study results with previous water quality monitoring projects.

2. METHODOLOGY

A total of 19 rainfall simulations were undertaken on horticultural and grazing properties across seven locations (soil types; Figure 1) from 9th – 16th April 2015. These simulations represented a range of land uses and management practices, as outlined in the following section.

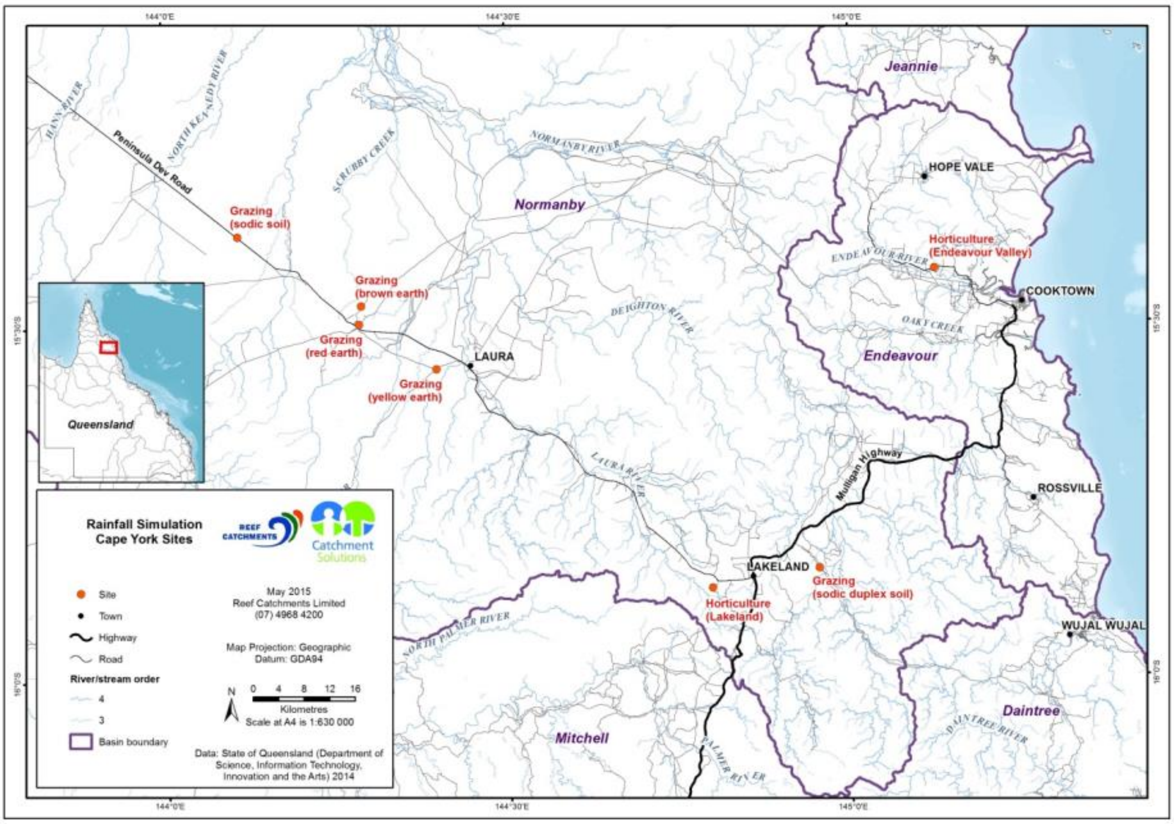

Figure 1 Major rivers and river basins, towns, and the location of the rainfall simulation sites

2.1. Site descriptions – horticulture properties

The sites, and the management practices investigated, are briefly described in Table 1. A photo of each site (rainfall simulation plot) is shown in Appendix 1. Further details are outlined below.

2.1.1. Lakeland

The Lakeland horticulture site was located approximately 6 km west of Lakeland on a Burn soil (Krasnozem). This soil is a well-drained, highly permeable deep uniform red clay of level to gently undulating plains. Prior to clearing for horticultural development, this soil type would have supported Eucalypt woodlands. The management practices investigated at this site were bananas (row and interrow), cereal cropping (fallow), and an ungrazed pasture. Although this soil type represents only a very small proportion of Cape York Peninsula, it is a very important cropping soil for the region.

2.1.2. Endeavour Valley

The Endeavour River horticulture site was located approximately 15 km NW of Cooktown on an Endeavour soil (Krasnozem). Similar to the Lakeland site, this soil is a well-drained, highly permeable deep red structured soil. Prior to clearing for horticultural development, this soil type would have supported closed forests or Eucalypt woodlands. The management practices investigated at this site were dragon fruit (row and interrow) and star apple (row and interrow).

Table 1 Soil name, soil concept and land management practices studied at each rainfall simulation site

Site	Soil name (Great Soil Group)	Soil concept	Land management practices studied
Horticulture properties			
Lakeland	Burn (Euchrozem / Krasnozem)	Deep uniform red structured clay soils with nodules formed on basalt	Banana (row and interrow), cropping (fallow) and pasture (ungrazed)
Endeavour Valley	Endeavour (Krasnozem / Euchrozem)	Deep gradational or occasionally uniform red structured soil formed on basalt	Dragon fruit (row and interrow) and star apple (row and interrow)
Grazing properties			
Yellow earth	Clark (Yellow Earth)	Deep bleached gradational yellow massive soils on residual sands	Pasture and road [1]
Red earth	Emma (Red Earth)	Deep gradational massive red soils formed on sandstone	Pasture (ungrazed) and road
Brown earth	Myall (Xanthozem)	Deep uniform or gradational yellow structured clay soils formed on siltstone, mudstone or claystone	Pasture and road
Sodic soil	Hann (Soloth / Gleyed Podzolic)	Deep bleached duplex soils on footslopes and drainage depressions in residual sands	Pasture and road
Sodic duplex soil	Gibson (Solodic / Soloth)	Deep duplex sodic yellow or grey soils on colluvia and pediments from greywacke and slate	Pasture, road and gully head

[1] Roads in the context of this report are internal property roads

2.2. Site descriptions – grazing properties

The sites, and the management practices investigated, are briefly described in Table 1. A photo of each site (rainfall simulation plot) is shown in Appendix 1. Further details are outlined below.

2.2.1. Yellow earth

This site was located approximately 5 km west of Laura on a Clark soil (Yellow Earth). This soil can be described as a moderately well-drained, moderately permeable deep bleached gradational yellow massive soil of gently undulating plains to undulating rises. This soil type represents approximately 18% of Cape York Peninsula. Vegetation consisted of Eucalypt and Melaleuca woodlands, with an understorey of native grasses. The management practices investigated at this site were pasture (grazed) and road.

2.2.2. Red earth

This site was located approximately 18 km NW of Laura on an Emma soil (Red Earth). This soil can be described as a well-drained, highly permeable deep gradational massive red soil of gently undulating plains to undulating rises. This soil type represents approximately 13% of Cape York Peninsula. Vegetation consisted of tall Eucalypt woodlands with an understorey of grasses (Panicum, Setaria and black spear). The management practices investigated at this site were pasture (not recently grazed) and a road.

2.2.3. Brown earth

This site was located approximately 20 km NW of Laura on a Myall soil (Xanthozem). This soil can be described as an imperfectly drained, slowly permeable deep mottled yellow structured clay soil of gently undulating plains to undulating rises. Vegetation consisted of Eucalypt woodlands with an understorey of grasses (black spear and grader grass) and stylo. The management practices investigated at this site were pasture (grazed) and a road.

2.2.4. Sodic soil

This site was located approximately 42 km NW of Laura on a Hann soil (Soloth/Gleyed Podzolic). This soil can be described as a poorly drained, slowly permeable deep bleached duplex soil on footslopes of gently undulating plains or undulating rises. This soil type represents approximately 17% of Cape York Peninsula. Vegetation consisted of Melaleuca and Eucalypt woodlands with an understorey of native grasses. The management practices investigated at this site were pasture (grazed) and a road.

2.2.5. Sodic duplex soil

This site was located approximately 11 km east of Lakeland on a Gibson soil (Solodic/Soloth). This soil can be described as a poorly drained, slowly permeable deep duplex soil on footslopes of rises and hillslopes. Vegetation consisted on Eucalypt woodlands with an understorey of native grasses. The management practices investigated at this site were pasture (grazed), a road and a gully head scald.

2.3. Rainfall simulator and plot setup

Each rainfall simulation plot was 1.5 m x 1.5 m, with the edge of each plot bound by 3 mm thick metal plates driven approximately 75 mm into the soil (leaving 75 mm above the soil surface). Runoff from each plot was directed to the middle of the plot front via a metal gutter (example shown in Figure 2). Plots on the same soil type were established close proximity to each other to minimise spatial error due to changes in soil properties, etc. An example is shown in Figure 3.

Figure 2 A typical rainfall simulation plot, 1.5 m x 1.5 m bounded by metal plates, with runoff collected from the outlet of the gutter at the front of the plot


Figure 3 A typical site (sodic soil) showing the close proximity of plots – road plot in the foreground, and the simulator set up on the pasture plot behind it

Simulated rainfall was applied at a rate of approximately 80 mm/hr for one hour (equivalent to ~1 in 7 year return interval for Endeavour Valley, ~1 in 10 year return interval for sites around Lakeland, and ~1 in 17 year return interval for sites north of Laura). The rainfall simulator (Figure 4), one module similar to that described by Loch et al. (2001), applied rain with drop sizes and energy consistent with natural rainfall in eastern Australia. Runoff rates were manually measured from the outlet of each plot, starting 2 minutes after runoff commenced, by recording the time taken to fill a measured volume. Water quality samples were collected at 5 or 10 minute intervals (6 samples collected from each simulation run), depending on when runoff commenced. The supply water for the rainfall simulator was sourced from tanks on each property, and a sample collected for water quality analysis. All water samples were chilled on collection, and sub-sampled and filtered at the end of each day. Nutrient samples were then frozen, and the sediment samples kept cool. All water samples were submitted for analysis to the NATA accredited Water and Waste Laboratories, Mackay Regional Council on 21st April 2015, and analysed for electrical conductivity, sediment and nutrient (total and filtered) concentrations.

Analysis of the source water showed that concentrations of ortho-P were detected in the water used for the Lakeland and Endeavour Valley sites (Table 2). Detectable concentrations of NO_x-N were found in the Endeavour Valley (0.03 mg/L) and grazing (0.13 mg/L) source water. Low concentrations of ammonia-N and TKN were detected in the water used at the sodic duplex soil sites. This water had the lowest conductivity (comparable to rainfall), with other sources 4-9 times higher.

Figure 4 A typical rainfall simulation setup, showing the plot set up beneath the simulator, and water supply

Table 2 Quality of the water supplied to the rainfall simulator at each site

Site	Conductivity (µS/cm)	TN [2] (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Lakeland	949	<0.2	<0.2	<0.01	<0.01	<0.1	0.01
Endeavour Valley	616	0.03	<0.2	<0.01	0.03	<0.1	0.05
Grazing [1]	433	0.13	<0.2	<0.01	0.13	<0.1	<0.01
Sodic duplex soil	105	0.50	0.5	0.03	<0.01	<0.1	<0.01

[1] The same water source was used for the yellow, red and brown earth sites, and the sodic soil site.
[2] It should be noted that TN is a calculation (TKN+NO_x-N). Due to non-detections, in some instances, TN may be reported as being lower than TKN. As a result, calculated loads may also be lower (or TKN+NO_x-N is different to TN).

2.4. Load calculations

For runoff water quality loads, linear interpolation was used to estimate concentrations between sampling points. The concentrations measured in the first sample were used for the beginning of the event, and concentrations from the last sample were reduced to half by the end of the event (see example in Figure 5). Water quality loads were then calculated for each minute of runoff, and summed to calculate a load from each simulation plot. For water quality concentrations that were below the limit of reporting, a value of half the limit of reporting value was used. Water quality loads applied in the source water were not deducted from the runoff loads due to the generally low values, and the majority of NO_x-N runoff concentrations at the grazing sites were lower than those applied in the source water. An event mean concentration (EMC) was then calculated:

$$\text{EMC (mg/L)} = (\text{Water quality load in runoff (kg) / Discharge (L)}) \times 10^6$$

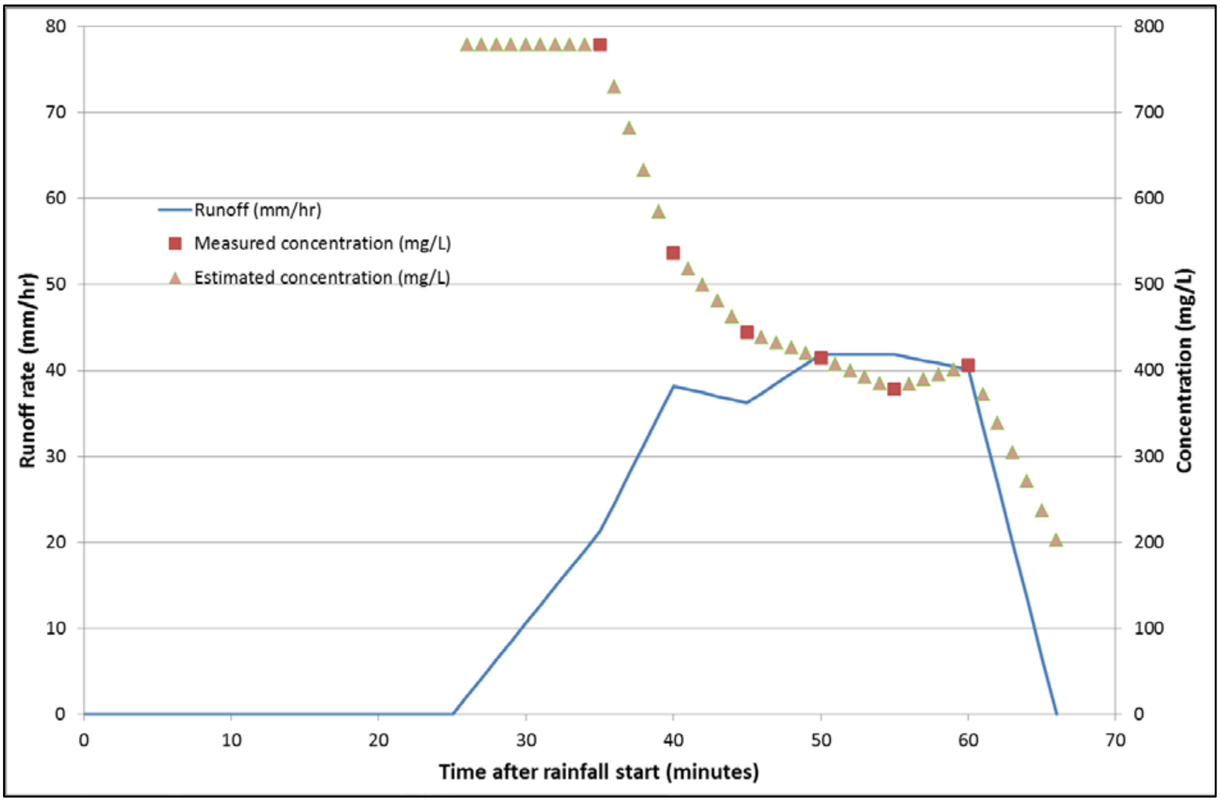

Figure 5 Example of estimated water quality concentrations at one minute intervals, based on measured concentrations at five minute intervals

3. RESULTS

The results presented here summarise the runoff and water quality loads (and EMC) from each rainfall simulation plot. Concentration data for each discrete water sample are given in Appendix 2.

It should be noted that when interpreting the results reported here, they represent a single point in time (e.g. a point in time after a nutrient application). Undertaking rainfall simulations at a different point in time may produce differing results, and therefore interpretations.

3.1. Horticulture property sites

The rainfall simulations undertaken on the horticultural properties represent a range of management practices on highly permeable soils (Table 1). This gave a variety of soil conditions (and surface cover) that impacted runoff volumes and water quality loads.

3.1.1. Runoff

Plots that were not impacted by soil compaction (Lakeland banana row and ungrazed pasture) did not run off after 80 mm of applied rainfall (Table 3). Although not part of the methodology, an additional 60 mm of rainfall (rainfall rate increased to 120 mm/hr for 30 minutes) was applied to the pasture plot (total of 140 mm rainfall in 1.5 hours) and still produced no runoff. In contrast to the banana row, the banana interrow had compacted wheel tracks, and produced 49 mm runoff. The fallow cropping plot produced 31 mm runoff. The dragon fruit plots at Endeavour Valley site had a much lower soil water deficit than the Lakeland sites, therefore ran off more (Table 3).

Table 3 Time to runoff, runoff depth, peak runoff rate, and infiltration for the horticulture property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Time to runoff (minutes)	Runoff (mm)	Final runoff rate (mm/hr)*	Infiltration (mm)
Lakeland				
Banana row	>60	0	0	80
Banana interrow	3	49	57	31
Cropping	12	31	53	49
Pasture	>60	0	0	80
Endeavour Valley				
Dragon fruit row	4	54	59	26
Dragon fruit interrow	2	59	63	21
Star apple row	13	20	33	60
Star apple interrow	3	51	57	29

* Averaged over last 10 minutes of rainfall

3.1.2. Water quality

The Lakeland banana interrow plot produced the highest loads of all measured water quality parameters (Table 4 and Table 5), which is not surprising given the nutrient inputs into this system. Concentrations of TSS measured from the dragon fruit plots were much lower than all other plots studied (Table 4) due to the high ground cover levels. Even though runoff was high, these plots only produced ~50 kg/ha of sediment loss due to the low concentrations.

When comparing row and interrow nitrogen and phosphorus concentrations at the Endeavour River sites, concentrations from the dragon fruit row were approximately double that of the interrow (Table 4 and Table 5), presumably reflecting the banding of nutrients to the row. In contrast, the star apple interrow concentrations were higher than the row. This may be due to the higher runoff and TSS concentrations from the interrow.

Table 4 Runoff depth, event mean concentrations and loads for TSS, TP and ortho-P for the horticulture property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Runoff	TSS		TP		Ortho-P	
	(mm)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)
Lakeland							
Banana row	0	-	-	-	-	-	-
Banana interrow	49	2304	1122	6.27	3.05	0.28	0.13
Cropping	31	2160	673	4.97	1.55	0.11	0.023
Pasture	0	-	-	-	-	-	-
Endeavour Valley							
Dragon fruit row	54	89	48	0.16	0.09	0.12	0.07
Dragon fruit interrow	59	90	53	0.06	0.03	0.06	0.03
Star apple row	20	183	36	0.05	0.01	0.02	<0.01
Star apple interrow	51	254	131	0.32	0.16	0.03	0.01

Table 5 Runoff depth, event mean concentrations and loads for TN, TKN, ammonia-N and NO_x-N for the horticulture property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Runoff	TN		TKN		Ammonia-N		NO_x-N	
	(mm)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)
Lakeland									
Banana row	0	-	-	-	-	-	-	-	-
Banana interrow	49	11.96	5.82	11.57	5.63	0.08	0.04	0.40	0.19
Cropping	31	9.19	2.87	9.08	2.83	0.09	0.03	0.11	0.04
Pasture	0	-	-	-	-	-	-	-	-
Endeavour Valley									
Dragon fruit row	54	1.26	0.68	1.11	0.60	0.04	0.02	0.17	0.09
Dragon fruit interrow	59	0.66	0.39	0.61	0.36	0.01	0.01	0.05	0.03
Star apple row	20	1.08	0.22	1.05	0.21	0.02	<0.01	0.06	0.01
Star apple interrow	51	3.35	1.72	3.26	1.68	0.03	0.01	0.08	0.04

3.1.3. Land use comparison

On a land use basis (assuming 50:50 split between row and interrow for row crops), bananas and cropping produced very similar water quality loads (higher NO_x-N from bananas), and higher than star apple and dragon fruit (Table 6). As mentioned previously, the pasture site did not run off. Across all of these cropping land uses, total nitrogen loads were dominated by organic nitrogen (80-95%). It was similar for phosphorus (83-99%), with the exception of dragon fruit (33%). This may be due to the rates of phosphorus applied to dragon fruit, or the low rate of soil erosion.

Table 6 Runoff (mm) and water quality loads (kg/ha) for bananas, cropping, dragon fruit and star apple

Land use	Runoff (mm)	TSS (kg/ha)	TP (kg/ha)	Ortho-P (kg/ha)	TN (kg/ha)	TKN (kg/ha)	Ammonia-N (kg/ha)	NO_x-N (kg/ha)
Banana	25	560	1.53	0.07	2.91	2.82	0.02	0.10
Cropping	31	673	1.55	0.03	2.87	2.83	0.03	0.04
Pasture	0	0	0	0	0	0	0	0
Dragon fruit	57	51	0.06	0.05	0.54	0.48	0.02	0.06
Star apple	36	84	0.09	<0.01	0.97	0.95	<0.01	0.03

3.2. Grazing property sites

The rainfall simulations undertaken on the grazing properties represent a range of soil types and management practices (mainly pasture vs. internal property roads) (Table 1). This gave a variety of soil conditions (and surface cover) that impacted runoff volumes and water quality loads.

3.2.1. Runoff

Runoff from the grazing property sites ranged from nil (red earth pasture, ungrazed) to 80 mm (gully head on sodic duplex soil) (Table 7). Of the pasture sites that did run off, runoff ranged from 10-48 mm. Time from commencement of rainfall to runoff ranged from 6-26 minutes. The brown earth pasture took the longest to run off (26 minutes) and had the lowest final runoff rate (18 mm/hr), leading to the least runoff (10 mm). In contrast, the sodic duplex soil pasture produced the most runoff (48 mm) due to the relatively quick onset of runoff (6 minutes) and relatively high runoff rate (62 mm/hr).

Roads (bare internal property roads) produced 1.5 to 7.7 times more runoff than pasture on the same soil type, excluding the red earth (Table 7). This was due to the quicker onset of runoff (1-4 minutes) and the higher runoff rates (63-77 mm/hr). Similar to the pasture situation, the red earth road ran off the least of all roads (63 mm), even though runoff commenced in 3 minutes and the final runoff rate was relatively high (68 mm/hr).

Table 7 Time to runoff, runoff depth, final runoff rate, and infiltration for the grazing property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Time to runoff (minutes)	Runoff (mm)	Final runoff rate (mm/hr)*	Infiltration (mm)
Yellow earth (pasture)	11	21	28	59
Yellow earth (road)	2	72	75	8
Red earth (pasture)	>60	0	0	80
Red earth (road)	3	63	68	17
Brown earth (pasture)	21	10	18	70
Brown earth (road)	4	77	80	3
Sodic soil (pasture)	26	20	41	60
Sodic soil (road)	1	68	73	12
Sodic duplex (pasture)	6	48	62	32
Sodic duplex (road)	4	74	77	6
Sodic duplex (gully head)	1	80	80	<1

* Averaged over last 10 minutes of rainfall

Of all the grazing property sites, the gully head at the sodic duplex soil site ran off the most. There was no measurable difference between rainfall applied and runoff (Table 7). This plot had a smooth surface, no surface cover, and its soil surface had already been eroded away. When the plot edges were removed from this plot, the rainfall had only infiltrated a few millimetres.

3.2.2. Water quality

Sediment loss (TSS) from pasture ranged from 24-221 kg/ha (excluding the ungrazed red earth pasture that did not run off) (Table 8), which was less than half of that produced from the Lakeland banana and cropping sites (Table 6). The brown earth pasture produced the least sediment loss (24 kg/ha) due to the lower runoff and lowest TSS concentration (240 mg/L). Concentrations of TSS at other pasture sites were similar (317-515 mg/L), producing a sediment loss of 93 (sodic soil) to 221 kg/ha (sodic duplex soil).

Roads produced 16-28 times more sediment than pasture on the same soil type, except for the brown earth (120 times more) (Table 8). This increase in sediment loss from roads was due to a combination of more runoff and higher TSS concentrations (8-15 times higher than pasture) due to the smooth, bare soil surface.

The TSS concentration produced from the gully head on the sodic duplex soil was more than double that from the road, and ~25 times more than the pasture. This produced 9260 kg/ha sediment loss from the gully head, ~42 times more than the pasture.

Table 8 Runoff depth, event mean concentrations and loads for TSS, TP and ortho-P for the grazing property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Runoff	TSS		TP		Ortho-P	
	(mm)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)
Yellow earth (pasture)	21	515	106	0.12	0.02	0.03	0.01
Yellow earth (road)	72	4120	2950	0.34	0.24	0.14	0.10
Red earth (pasture)	0	-	-	-	-	-	-
Red earth (road)	63	317	199	12.26	7.69	1.41	0.89
Brown earth (pasture)	10	240	24	0.10	0.01	0.03	<0.01
Brown earth (road)	77	3730	2880	2.45	1.90	0.01	0.01
Sodic soil (pasture)	20	477	93	0.08	0.02	0.06	0.01
Sodic soil (road)	68	3790	2580	0.17	0.12	0.07	0.05
Sodic duplex (pasture)	48	459	221	0.42	0.20	0.04	0.02
Sodic duplex (road)	74	4970	3650	1.42	1.05	0.01	<0.01
Sodic duplex (gully head)	80	11300	9260	3.09	2.54	<0.01	<0.01

Similar to TSS concentrations, phosphorus concentrations from roads were higher than pasture on the same soil types (Table 8), presumably due to the higher sediment concentrations. The red earth road produced the highest phosphorus concentrations (and therefore loads) of the entire study. Phosphorus concentrations were generally highly dominated by organic P (>90%), except for the yellow earth road (~50%) and the sodic soil road (38%).

The calculated NO_x-N EMC ranged from 0.03-0.13 mg/L for pasture, and 0.03-0.20 mg/L for roads (Table 9). The highest concentration ammonia-N EMC (0.26 mg/L) was detected at the brown earth site (as was the highest NOx-N concentration), which was 3-times higher than any of the horticultural sites. A possible cause for this high ammonia-N concentration could be cattle excrement when using this road as a cattle track (cattle were in the vicinity at the time of doing the rainfall simulation).

Concentrations of TKN (and therefore TN) were higher from roads than pasture on the same soil type (Table 9), except for the yellow earth. As would be expected from these largely undeveloped sites, organic nitrogen (TKN) comprised more than 95% of the TN.

Due to the high TSS concentrations produced from the gully head on the sodic duplex soil, loads of TKN and TN were ~7 times higher than those measured from the corresponding pasture site, and almost three times higher than measured from the road (Table 9).

Table 9 Runoff depth, event mean concentrations and loads for TN, TKN, ammonia-N and NO_x-N for the grazing property sites and management practices from one hour of simulated rainfall (80 mm/hr)

Site	Runoff	TN		TKN		Ammonia-N		NO_x-N	
	(mm)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)	(mg/L)	(kg/ha)
Yellow earth (pasture)	21	2.18	0.45	2.11	0.44	0.02	<0.01	0.09	0.02
Yellow earth (road)	72	2.10	1.51	1.98	1.42	0.05	0.03	0.12	0.09
Red earth (pasture)	0	-	-	-	-	-	-	-	-
Red earth (road)	63	1.68	1.06	1.64	1.03	0.09	0.05	0.06	0.04
Brown earth (pasture)	10	1.50	0.15	1.37	0.14	0.03	<0.01	0.13	0.01
Brown earth (road)	77	14.2	11.0	14.0	10.9	0.26	0.20	0.20	0.16
Sodic soil (pasture)	20	1.12	0.22	1.02	0.20	0.01	<0.01	0.10	0.02
Sodic soil (road)	68	1.93	1.31	1.83	1.24	<0.01	<0.01	0.09	0.06
Sodic duplex (pasture)	48	2.24	1.08	2.23	1.07	0.05	0.02	0.03	0.01
Sodic duplex (road)	74	3.92	2.90	3.90	2.88	0.03	0.03	0.03	0.02
Sodic duplex (gully head)	80	9.66	7.94	9.65	7.93	0.04	0.03	0.03	0.03

4. DISCUSSION

This section will attempt to compare results from this rainfall simulation study with previous water quality studies in similar industries and/or within the Normanby River catchment. As mentioned in Section 3, it should be noted that the results of this study represent a single point in time (e.g. a point in time after a nutrient application). Comparisons to longer term studies should therefore be treated with caution.

4.1. Intensification of land use

The sites studied at Lakeland and Endeavour Valley provide a useful comparison of the impacts of land use intensification on runoff and water quality. The soils are well-drained, highly permeable deep uniform red clay therefore runoff in its undeveloped state would be low. The pasture and road sites also provide a comparison of the impacts of development (roads being an entirely anthropogenic source of sediments and nutrients).

Although we did not simulate an undeveloped site, the pasture site at Lakeland (cleared but not grazed) provided a close alternative and produced no runoff from 80 mm of simulated rainfall. The banana row also produced no runoff due to the lack of soil compaction (good soil structure) and good ground cover. The cropping site (fallow, with ~40% stubble cover) produced 31 mm runoff. The banana interrow ran off the most (49 mm) due to the compacted wheel track. On a block basis (50:50 split of row and interrow for bananas), the runoff from bananas was slightly less than cropping (25 mm and 31 mm, respectively). Although the development of these soils for horticulture has increased runoff, it is within the range of runoff (0-48 mm) produced from pastures on the soil types studied. The Endeavour Valley sites produced variable runoff due to variable soil moisture content.

Similar to runoff, sediment loss also increased with land use intensification – nil from pasture, and up to ~650 kg/ha from cropping and bananas on a block basis. This range is much higher than the pasture sites studied (0-221 kg/ha), and highlights the need to maintain high cover levels on these soils to minimise sediment loss. Evidence of this was shown in the pasture vs. road comparisons, where roads produced at least 16 times more sediment loss than pasture, and at least 3 times that of cropping and bananas. This is also shown in the Endeavour Valley sites where sediment loss was 50-84 kg/ha due to the well-grassed interrows.

A similar response was also measured for nitrogen and phosphorus. On a block basis, cropping and bananas produced ~2.9 kg/ha of TN and 1.5 kg/ha of TP in runoff. Again, these are higher than the pasture sites, but within the range of TN and TP loads measured from roads (10.9 kg/ha of TN from the brown earth road, and 7.65 kg/ha of TP from the red earth road).

4.2. Comparison to a banana runoff study

A three year runoff and water quality study undertaken at South Johnstone (Armour et al., 2013) provides a useful comparison for the results obtained in our study.

The sediment loss measured in our study was much higher than that measured in single runoff events reported in Armour et al. (2013). They concluded that wheel ruts from machinery were a major source of sediment during extended wet seasons. The banana row in our study did not run off, therefore comparisons can only be made using our interrow data. The interrow plot consisted of a bare, compacted wheel rut that was estimated to occupy ~20% of the plot area (compared to ~5% if the entire 6 m row width is used as in Armour et al., 2013). This, along with our small plot area (2.25 m^2 compared to ~650 m^2 in Armour et al., 2013), could be the source of significant erosion differences. When using a block approach (50:50 split between row and interrow), our results (560 kg/ha) are more comparable to those of Armour et al. These results highlight the challenge of interrow management in the banana industry, where there is a need for continual trafficking in all weather conditions for routine farm management.

Annual runoff losses of TN and TP in the South Johnstone study were 4-60 kg/ha and 2-26 kg/ha, respectively (Armour et al. 2013). Our results (using the block approach) from a single rainfall simulation event were 2.91 kg/ha and 1.50 kg/ha for TN and TP, respectively, which were within the range of single events measured by Armour et al. (2013). Both studies found that the majority of N and P lost were in the organic form, with inorganic N and P providing minor contributions to the total N and P losses in runoff.

4.3. Sediment loss from roads

The generation of sediment loss from unsealed roads (an entirely anthropogenic sediment source) is largely unknown in the wet-dry tropics of northern Australia. Gleeson and Brooks (2013) measured the suspended sediment generated from three unsealed road segments within the Normanby River catchment over a three month period during the 2011/12 wet season. Using rising stage and hand held sediment samplers, they measured suspended sediment concentrations in the range of 113-13509 mg/L, with a mean production of 1779 mg/L. In our rainfall simulation study, the range of TSS concentrations (EMC) was similar, ranging from 317-4970 mg/L, or up to 11300 mg/L if the gully head of the sodic duplex soil is included (Table 8). Individual discrete concentrations ranged from 274-6102 mg/L, or 15462 mg/L if the gully head of the sodic duplex soil is included (Appendix 2). Both of these studies show that unsealed roads can be major contributors to sediment loss across a catchment.

4.4. Gully erosion in the Normanby Basin

A sediment sourcing study undertaken by Brooks et al. (2013) in the Normanby basin quantified the contribution of small alluvial tributaries and alluvial gullies to the total suspended sediment load delivered to Princess Charlotte Bay. This analysis indicated that gully erosion accounted for ~37% of the load, with alluvial gullies comprising ~24% and colluvial gullies 13% of the total.

Although the results of Brooks et al. (2013) cannot be directly compared to our rainfall simulation study, our study did show that a gully head scald on a sodic duplex soil is a significant source of erosion. Sediment loss was 9260 kg/ha, 2.5 times higher than a road and ~42 times higher than pasture (221 kg/ha) on the same soil type. The sediment loss from pasture on this sodic duplex soil was double that of the next highest sediment loss from a pasture site (106 kg/ha from pasture on yellow earth). These results highlight the fragile nature of these soils, and the importance of good pasture management and maintaining ground cover to reduce soil erosion.

5. CONCLUSIONS

This rainfall simulation study has provided a comprehensive data set on runoff and water quality from a number of soil types, land uses and management practices. The combination of soil types and management showed that uncompacted highly permeable soils did not run off (banana row and ungrazed pastures), ranging up to almost 100% runoff from a scalded gully head on a sodic duplex soil.

Sediment loss from those plots that ran off ranged from 24 kg/ha (brown earth pasture; low runoff) to 9260 kg/ha (gully head on sodic duplex soil; high runoff and high sediment concentration). Roads produced at least 16 times more sediment loss than pasture on the same soil type due to more runoff and higher sediment concentrations. These results highlight the need for erosion management of roads, and maintaining pasture cover on fragile sodic soils to prevent gully initiation.

Total N and P loads in runoff from horticultural sites were within the range of the loads measured from the pasture sites. Roads produced more TN and TP than pasture, due to the higher runoff and sediment concentrations. Runoff of nitrogen and phosphorus was dominated by organic forms at all sites, except the dragon fruit site which may have been due to applied fertiliser.

In summary, the results of this rainfall simulation study are supported by those observed from other studies. The results highlight the potential for elevated sediment and nutrient runoff losses if the soil type is not managed appropriately.

6. REFERENCES

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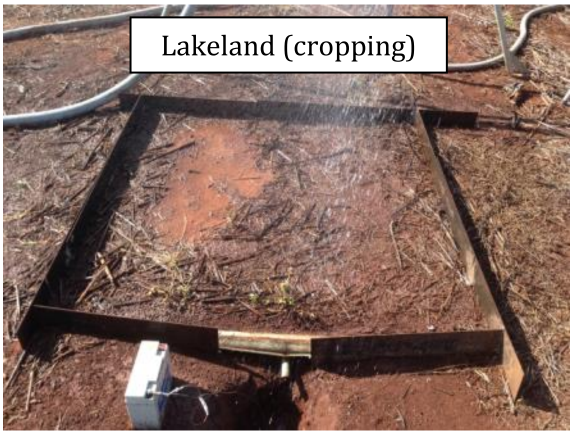
APPENDIX 1 – Surface condition of each rainfall simulation plot

a) Horticulture property sites

Lakeland (banana row)

Lakeland (banana interrow)



Lakeland (cropping)

Lakeland (pasture)

Endeavour Valley (dragon fruit row)

Endeavour Valley (dragon fruit interrow)

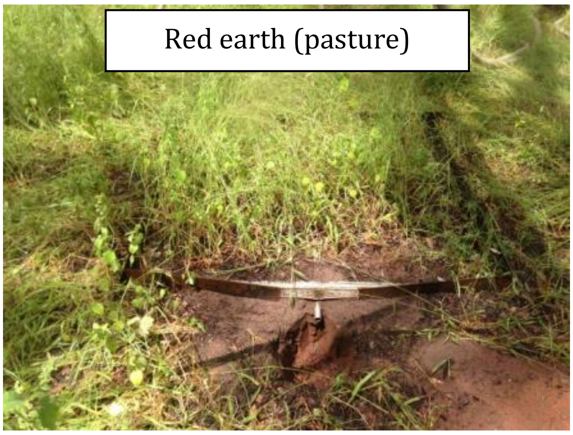
Endeavour Valley (star apple row)

Endeavour Valley (star apple interrow)

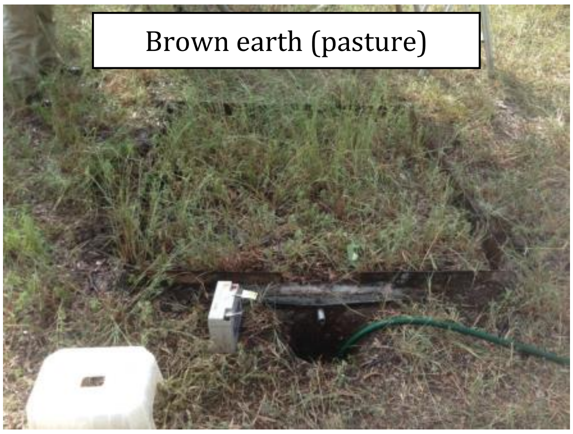

Yellow earth (road)


Yellow earth (pasture)


Red earth (road)

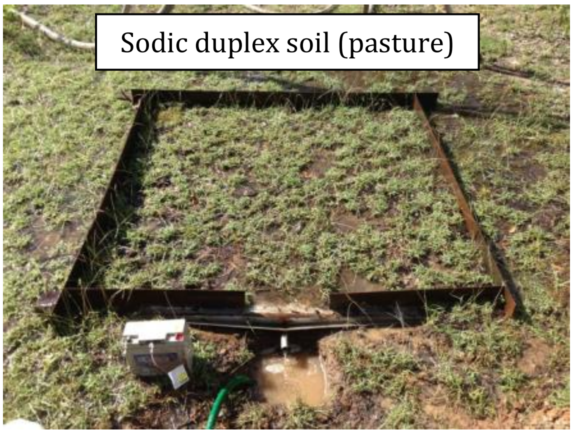

Red earth (pasture)


Brown earth (road)


Brown earth (pasture)


Sodic soil (road)


Sodic soil (pasture)


Sodic duplex soil (pasture)


Sodic duplex soil (gully head)


Sodic duplex soil (road)

APPENDIX 2 – Laboratory results

a) Source water

Water source	Conductivity (µS/cm)	TSS (mg/L)	TN (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Lakeland	949	4	<0.2	<0.2	<0.01	<0.01	<0.1	0.01
Endeavour Valley	616	120	0.03	<0.2	<0.01	0.03	<0.1	0.05
Grazing [1]	433	16	0.13	<0.2	<0.01	0.13	<0.1	<0.01
Sodic duplex soil	105	5	0.50	0.5	0.03	<0.01	<0.1	<0.01

[1] The same water source was used for the yellow, red and brown earth sites, and the sodic soil site

b) Runoff

Time after rainfall start (minutes)	Conductivity (µS/cm)	TSS (mg/L)	TN (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Lakeland (banana row) – no runoff								
Lakeland (banana interrow)								
10	1015	2582	14.1	13.6	0.14	0.6	7.3	0.45
20	1032	2478	13.32	12.9	0.06	0.40	6.4	0.22
30	1026	2344	11.85	11.4	0.07	0.42	6.4	0.33
40	1011	2100	8.53	8.1	0.06	0.45	4.6	0.21
50	1020	2118	10.92	10.7	0.07	0.22	5.6	0.18
60	1002	2212	13.53	13.3	0.07	0.21	7.8	0.24
Lakeland (cropping)								
20	1003	2626	15.82	15.7	0.13	0.14	7.7	0.17
25	1000	2300	10.55	10.4	0.11	0.19	6.6	0.16
30	991	2708	11.83	11.7	0.11	0.12	5.8	0.15
40	975	1528	5.85	5.8	0.07	0.10	3.7	0.06
50	1006	1902	6.23	6.1	0.08	0.09	3.3	0.09
60	995	2384	9.21	9.1	0.06	0.09	5.1	0.08
Lakeland (pasture) – no runoff								
Endeavour Valley (dragon fruit row)								
10	504	198	3.24	2.9	0.09	0.35	0.5	0.21
20	533	120	1.44	1.3	0.06	0.19	0.2	0.15
30	533	80	0.90	0.8	0.03	0.12	0.1	0.09
40	557	44	0.71	0.6	0.03	0.13	<0.1	0.10
50	571	44	0.65	0.5	0.02	0.11	<0.1	0.10
60	573	42	0.58	0.5	0.02	0.11	<0.1	0.09

Time after rainfall start (minutes)	Conductivity (µS/cm)	TSS (mg/L)	TN (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Endeavour Valley (dragon fruit interrow)								
10	556	112	1.30	1.2	0.01	0.06	<0.1	0.06
20	569	58	0.66	0.6	0.01	0.05	<0.1	0.05
30	574	138	0.57	0.5	0.02	0.04	0.1	0.10
40	571	106	0.34	0.3	0.01	0.05	<0.1	0.04
50	590	44	0.49	0.5	0.01	0.04	<0.1	0.04
60	594	80	0.52	0.5	0.03	0.05	<0.1	0.04
Endeavour Valley (star apple row)								
20	536	328	2.03	2.0	0.03	0.07	<0.1	0.02
25	537	276	2.07	2.0	0.02	0.08	<0.1	0.03
30	537	304	1.22	1.2	0.02	0.04	<0.1	0.02
40	548	116	0.73	0.7	0.01	0.06	<0.1	0.03
50	550	124	0.62	0.6	0.02	0.06	<0.1	0.02
60	555	102	0.96	0.9	0.02	0.06	<0.1	0.02
Endeavour Valley (star apple interrow)								
10	560	428	6.01	5.9	0.05	0.10	0.5	0.03
20	576	338	3.90	3.8	0.03	0.07	0.4	0.03
30	578	192	2.90	2.8	0.02	0.08	0.2	0.03
40	588	176	2.87	2.8	0.02	0.07	0.3	0.03
50	588	224	2.37	2.3	0.02	0.07	0.3	0.03
60	593	148	1.77	1.7	0.02	0.08	0.2	0.02
Yellow earth (pasture)								
15	420	750	2.23	2.1	0.05	0.13	0.2	0.08
20	408	710	3.04	3.0	0.04	0.07	0.2	0.02
30	412	828	3.02	3.0	0.03	0.04	0.2	0.01
40	419	324	1.77	1.7	0.02	0.08	0.1	0.01
50	420	432	1.78	1.7	0.01	0.13	<0.1	0.01
60	423	222	1.52	1.4	<0.01	0.13	<0.1	0.10
Yellow earth (road)								
10	437	4788	3.40	3.3	0.07	0.07	0.5	0.21
20	435	5734	3.02	2.9	0.07	0.09	0.5	0.15
30	440	3596	1.87	1.7	0.04	0.14	0.3	0.15
40	444	4308	1.73	1.6	0.04	0.14	0.3	0.11
50	443	3028	1.13	1.0	0.03	0.14	0.2	0.10
60	447	2996	1.41	1.3	0.03	0.15	0.2	0.09
Red earth (pasture) – no runoff								

Time after rainfall start (minutes)	Conductivity (µS/cm)	TSS (mg/L)	TN (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Red earth (road)								
10	461	438	2.55	2.5	0.12	0.07	16.2	1.5
20	477	274	1.55	1.5	0.09	0.06	9.6	1.6
30	457	276	1.78	1.7	0.08	0.07	11.4	1.1
40	446	286	1.53	1.5	0.07	0.07	13.0	1.2
50	454	308	1.17	1.2	0.08	0.02	10.7	1.3
60	451	332	1.48	1.4	0.08	0.06	13.4	2.1
Brown earth (pasture)								
30	432	300	2.59	2.4	0.04	0.15	0.2	0.05
35	436	390	2.54	2.4	0.03	0.13	0.2	0.02
40	439	284	1.29	1.2	0.03	0.13	<0.1	0.02
45	442	154	0.81	0.7	0.03	0.13	<0.1	<0.01
50	450	186	0.99	0.9	0.03	0.10	<0.1	<0.01
60	457	160	0.98	0.8	0.04	0.14	<0.1	0.05
Brown earth (road)								
10	405	5878	24.35	24.1	0.44	0.28	3.6	0.02
20	404	3792	14.20	14.0	0.31	0.20	2.6	<0.01
30	405	3536	13.57	13.4	0.22	0.21	2.6	<0.01
40	402	3558	11.95	11.8	0.23	0.20	2.3	<0.01
50	414	2978	11.39	11.2	0.20	0.16	1.9	<0.01
60	424	2284	8.58	8.4	0.17	0.17	1.5	<0.01
Sodic soil (pasture)								
35	448	778	1.79	1.6	0.02	0.16	0.2	0.11
40	450	536	1.22	1.1	0.01	0.13	<0.1	0.08
45	433	444	1.14	1.0	<0.01	0.12	<0.1	0.07
50	429	414	0.93	0.8	0.01	0.13	<0.1	0.05
55	431	378	1.07	1.0	<0.01	0.06	0.1	0.02
60	436	406	0.81	0.8	<0.01	0.03	<0.1	0.02
Sodic soil (road)								
10	450	5014	1.76	1.6	<0.01	0.12	0.2	0.02
20	444	3874	1.73	1.6	<0.01	0.12	0.1	0.02
30	434	3690	0.84	0.8	<0.01	0.07	<0.1	0.01
40	434	3158	2.68	2.6	<0.01	0.05	0.3	0.18
50	433	3054	2.23	2.2	<0.01	0.08	0.2	0.12
60	448	3608	2.60	2.5	<0.01	0.13	0.2	0.10

Time after rainfall start (minutes)	Conductivity (µS/cm)	TSS (mg/L)	TN (mg/L)	TKN (mg/L)	Ammonia-N (mg/L)	NO_x-N (mg/L)	TP (mg/L)	Ortho-P (mg/L)
Sodic duplex soil (pasture)								
10	92	886	4.07	4.0	0.07	0.11	0.8	0.06
20	77	544	1.80	1.8	0.05	<0.01	0.4	0.04
30	79	500	3.29	3.3	0.04	<0.01	0.5	0.04
40	76	436	1.71	1.7	0.05	0.01	0.3	0.04
50	78	390	2.03	2.0	0.04	0.05	0.3	0.03
60	79	292	1.71	1.7	0.05	0.04	0.5	0.03
Sodic duplex soil (road)								
10	67	4932	7.18	7.1	0.04	0.06	2.6	<0.01
20	65	6102	3.31	3.3	0.03	0.05	1.3	<0.01
30	67	5960	3.03	3.0	0.04	<0.01	1.4	0.01
40	67	3428	1.50	1.5	0.04	<0.01	0.7	<0.01
50	68	5300	4.80	4.8	0.03	<0.01	1.4	<0.01
60	68	3930	4.03	4.0	0.03	0.03	1.2	<0.01
Sodic duplex soil (gully head)								
10	87	15462	11.56	11.6	0.04	<0.01	3.5	<0.01
20	87	12554	9.07	9.1	0.04	<0.01	3.4	<0.01
30	88	8690	7.39	7.3	0.04	0.05	2.0	<0.01
40	89	9394	8.76	8.7	0.04	0.05	2.4	<0.01
50	79	10678	12.01	12.0	0.05	0.05	4.1	<0.01
60	78	10080	8.59	8.6	0.04	0.04	3.1	<0.01

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